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RESEARCH MEMORANDUM

SOME EXPERIMENTS ON THE FLUTTER OF SWEPTBACK CANTILEVER WING MODELS AT MACH NUMBER 1.3

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

SOME EXPERIMENTS ON THE FLUTTER OF SWEPTBACK CANTILEVER WING MODELS AT MACH NUMBER 1.3

By W. J. Tuovila

SUMMARY

Flutter tests of sweptback cantilever wing models have been made in a small intermittent two-dimensional supersonic tunnel where the testing technique involved changing the structural parameters so that the models would flutter at the tunnel design Mach number of 1.3. Data for 21 models covering sweep angles from 30° to 60° and with varying parameters are included.

No attempt is made to correlate the data with analytical developments. However, reference values of flutter speed, obtained with a swept-wing flutter analysis based on two-dimensional incompressible flow, are compared with the experimental flutter speed in order to unify the results. The incompressible-flow flutter theory appears very conservative for the 30° to 45° sweptback models and is in reasonable agreement for the 60° sweptback models at Mach number 1.3. Caution should be observed in extrapolating these data to conditions other than those covered in the tests.

INTRODUCTION

Many present aircraft and missiles are being designed with sweptback wings for operation at transonic speeds and the designer is faced with a lack of theoretical and experimental information on the flutter of such wings in this speed range. A few initial experiments on the flutter of sweptback wings in the transonic speed range have been made by a technique involving the use of rocket-propelled vehicles and the results are reported in reference 1.

The present paper is devoted to the presentation of a limited amount of experimental results on the flutter of cantilever wings with sweepback at Mach number 1.3. These data were obtained with the aid of a wind-tunnel technique making use of an intermittent supersonic wind

tunnel with a test section designed to operate at Mach number 1.3. The technique used was that described in reference 2, which presents the results of a similar series of tests on unswept cantilever wings, and involves changing the structural parameters of the wing to yield flutter at the operating Mach number.

For the swept-wing tests reported herein, data on 21 models covering a sweep range from 30° to 60° were obtained. No attempt is made to correlate the data with any analytical developments. For convenience in the presentation of the results, however, reference values of flutter speed obtained with the use of two-dimensional incompressible-flow theory have been calculated. The use of these calculated reference values helps to unify the presentation of the results.

SYMBOLS

c	chord, inches, measured perpendicular to the leading edge
b	semichord, feet, measured perpendicular to the leading edge
l	length of model, inches, measured parallel to the leading edge
ρ	mass density of air in test section, slugs per cubic foot
t	thickness, inches
m	mass of wing, slugs per unit span
$1/\kappa$	mass-density ratio parameter $(m/\pi\rho b^2)$
I_α	mass moment of inertia of wing about elastic axis, slugs-feet² per unit span
x_o	elastic axis position in percent of chord from leading edge
x_1	wing center-of-gravity position in percent chord from leading edge
r_α	nondimensional radius of gyration of wing about elastic axis $\left(\sqrt{\frac{I_\alpha}{mb^2}}\right)$
f_e	experimental flutter frequency, cycles per second

f_h uncoupled first bending frequency, cycles per second

f_α uncoupled first torsion frequency, cycles per second

Λ angle of sweepback, degrees

ω theoretical flutter frequency, radians per second

ω_α $2\pi f_\alpha$

ω_e $2\pi f_e$

v_e experimental flutter velocity in feet per second, measured perpendicular to leading edge

v_Λ reference flutter velocity in feet per second, measured perpendicular to leading edge, based on incompressible two-dimensional flow (reference 3)

MODELS AND TEST METHODS

The models that were used to obtain data for the present paper were made of sitka spruce and were similar in construction to some of the models used in the tests of reference 2. Some of the geometric, physical, and mechanical properties of the models are listed in table 1. The ranges of some of these properties are: sweep angles, 30° to 60°; chord, measured perpendicular to the leading edge, 2 to 4.11 inches; length, 6 to 15.4 inches; mass density parameter, 37 to 216; center-of-gravity position, 25.8 to 58.2 percent chord; and elastic axis position, 32.0 to 74.4 percent chord. The elastic axis position as used herein was taken as the chordwise position measured perpendicular to the leading edge at the three-quarter span station at which a normal concentrated load produces no twist in a plane perpendicular to the leading edge of the wing at this station.

Presented also in table 1 are the uncoupled first bending mode frequencies and the uncoupled first torsional model frequencies. The uncoupled first bending mode frequency is taken as the coupled first bending mode frequency which was obtained by flicking the tip of the wing and recording the oscillations. The method used to evaluate approximately the uncoupled first torsional mode frequency is described in appendix A.

The models were mounted as cantilevers and were tested at a Mach number of 1.3 in an intermittent two-dimensional supersonic wind tunnel

having a 9.24-inch by 18.23-inch test section. The testing technique involved injecting the models into and retracting them from the tunnel while the flow was steady at Mach number 1.3. This technique was used to avoid possible flutter that might occur during the tunnel starting and stopping transients. It was, therefore, necessary to adjust the structural parameters of the models so that flutter would occur at the test Mach number 1.3 rather than to follow the usual procedure of determining the flutter speed which is associated with a given combination of parameters. Thus, if the model did not flutter when it was injected into the air stream, changes were made in some of the model parameters and injection was again made. This process was continued until the flutter border was found. On the other hand, if there was evidence of flutter while the model was being injected, the model was immediately retracted and the structural parameters changed. This process was also repeated until the flutter border was found. Some of the models, however, were tested in the transient speed range by leaving them in the tunnel while the tunnel velocity was increased slowly. A more detailed description of the test methods and photographs of the apparatus can be found in reference 2.

Most of the parameter changes were brought about by changing the center-of-gravity position and the torsional stiffness. The center-of-gravity position was changed by taping strips of lead foil to the leading or trailing edge of the model and the torsional stiffness was reduced by cutting uniformly spaced slits parallel to the air stream. The addition of lead foil to the model altered the airfoil section somewhat from the section shape listed in table 1. Reference 2 and other flutter tests, however, indicate that section shape may be of minor importance.

The flutter frequency, position of the model in the tunnel, and the static pressure in the test section were recorded simultaneously by a recording oscillograph.

RESULTS AND DISCUSSION

The experimental data on the 21 models tested are included in table 1. Also shown in this table are the values of the reference flutter-speed coefficient $\left(v_\Lambda/b\omega_\alpha\right)$ and the flutter-frequency ratio $\left(\omega_\Lambda/\omega_\alpha\right)$ that were obtained from a swept-wing flutter analysis that is based on incompressible two-dimensional flow. This analysis (see referenee 3) involved the use of a bending mode shape and a torsional mode shape and used a damping coefficient of 0.03 for both bending and torsion. For convenience in the presentation of the results, the ratio of the experimental flutter speed to this reference flutter speed was then found. This velocity ratio v_e/v_Λ is plotted against the angle of sweepback in figure 1. In the inspection

of this figure it should be kept in mind that, because of the technique used, all the data are for a Mach number of 1.3. It should also be kept in mind that the reference flutter speed is based on a first mode torsional frequency which is found approximately. The presentation of the results in the ratio form shown helps to indicate how well incompressible-flow theory applies at supersonic Mach number 1.3. The incompressible-two-dimensional-flow flutter analysis appears very conservative for the 30°, 35°, and 45° models and is in reasonable agreement for the 60° models.

A possible combined aspect ratio and sweepback effect was observed when some of the models were tested during the tunnel transient flow. Of the models so tested, the 60° sweptback models with length-chord ratios greater than 4 fluttered only at the top Mach number of 1.3. The 60° models with length-chord ratios less than 4 fluttered during the starting transient (subsonic speeds) as well as exhibiting a flutter-border condition at the top Mach number of 1.3. The 30° to 45° sweptback models also exhibited a subsonic flutter as well as flutter at Mach number 1.3.

Model number 15 presents an interesting case since it has a center-of-gravity position at 25.8 percent chord. This is usually adequate to prevent the flutter of unswept wings. However, with 60° sweepback this model fluttered. This result is consistent with incompressible-flow swept-wing flutter theory which shows that a center-of-gravity location at 25 percent chord does not eliminate the possibility of flutter of sweptback wings.

The results presented herein on the flutter test of 21 models at Mach number 1.3 may be useful in evaluating future analytical developments and also may be of direct use to designers. Caution should be observed in making use of the data for conditions which are not covered by these tests, particularly for wings having different mass-density parameter, aspect ratio, center-of-gravity location, and Mach number.

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APPENDIX A

UNCOUPLED FIRST TORSION FREQUENCY

Figure 2 illustrates the technique used to determine the uncoupled first torsion frequency. A yoke with a large inertia I_y is clamped near the wing tip and the uncoupled first torsion frequency f_y of the wing-yoke combination is excited while the model is supported at the elastic axis. It is then assumed that the following equations taken from appendix II of reference 4 may be used to calculate the uncoupled first torsion frequency of the wing alone.

$$GJ = \left(2\pi f_y\right)^2 l_1 \left(I_y + \frac{1}{3} I_w\right)$$

$$f_\alpha = \frac{1}{4l}\sqrt{\frac{GJ}{I_w/l}}$$

where

f_y torsional frequency with yoke

I_y polar moment of inertia of yoke about its center of gravity

I_w total polar moment of inertia of wing about the elastic axis (where the elastic axis is assumed straight and parallel to the leading edge)

For large angles of sweepback and low values of l/c, the accuracy of the calculated value of the uncoupled first torsion frequency f_α is uncertain since the length l_1, is taken arbitrarily as the length of the wing model center line measured from the yoke to the root. Strain gages at the root of each model were used in measuring the oscillations of the model.

REFERENCES

1. Lauten, William T., Jr., and Teitelbaum, J. M.: Some Experiments on the Flutter of Wings with Sweepback in the Transonic Speed Range Utilizing Rocket-Propelled Vehicles. NACA RM L50C03a, 1950.

2. Tuovila, W. J., Baker, John E., and Regier, Arthur A.: Initial Experiments on Flutter of Unswept Cantilever Wings at Mach Number 1.3. NACA RM L8J11, 1949.

3. Barmby, J. G., Cunningham, H. J., and Garrick, I. E.: Study of Effects of Sweep on the Flutter of Cantilever Wings. NACA TN 2121, 1950.

4. Den Hartog, J. P.: Mechanical Vibrations Third ed., McGraw-Hill Book Co., Inc., 1947.

TABLE I

MODEL PARAMETERS AND RESULTS

Parameters \ Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Λ	30	30	30	35	35	35	35	35	45	45	45	45	45	45	60	60	60	60	60	60	60
Section	(1)	65008	Cir. arc	65008	65008	65008	65008	65008	65010	65010	65010	65010	Cir. arc	Cir. arc	Cir. arc	Cir. arc	Cir. arc	(1)	(1)	(1)	(1)
c	4.11	2.59	3.54	2.59	2.59	2.59	2.59	2.59	2.06	2.06	2.06	2.06	2.19	2.19	3.13	3.06	1.53	2.0	2.0	2.0	2.0
l	6.54	6.9	6.92	7.21	7.21	7.21	7.21	7.21	8.48	8.48	8.48	8.48	8.5	8.5	15.4	12.5	12.0	8.0	8.0	6.0	6.0
l/c	1.59	2.66	1.95	2.78	2.78	2.78	2.78	2.78	4.10	4.10	4.10	4.10	3.88	3.88	4.93	4.08	7.84	4.0	4.0	3.0	3.0
t	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.266	0.266	0.21	0.14	0.13	0.08	0.09
x_1	48.0	44.5	50.0	40.1	40.1	44.5	44.5	52.0	36.3	44.5	44.5	50.2	50.0	58.2	25.8	34.9	34.0	33.6	35.5	37.2	45.5
x_0	47.0	32.0	55.0	36.3	32.5	37.9	36.3	37.9	43.6	44.5	47.7	51.5	52.4	58.7	66.0	73.5	63.2	63.0	56.0	74.3	74.4
$1/\kappa$	37.0	68.0	48.0	78.1	77.0	68.7	67.4	82.5	120	91.7	91.7	107	96.5	120	178	128	216	103	97	74	62
r^2_α	0.22	0.277	0.226	0.255	0.267	0.232	0.241	0.366	0.27	0.214	0.218	0.274	0.200	0.339	0.914	0.87	0.598	0.625	0.475	0.837	0.592
b	0.172	0.108	0.148	0.108	0.108	0.108	0.108	0.108	0.086	0.086	0.086	0.086	0.091	0.091	0.13	0.128	0.064	0.083	0.083	0.083	0.083
f_e	185	186	182	173	172	190	190	194	147	169	165	161	159	150	51	77.6	66	118	146	176	195
f_h	141	96	120	102	99	111	104	97	78	85	87	80	88	84	27	45	36.7	67	70	98.8	88
f_α	254	254	271	265	246	312	288	234	250	308	320	300	310	266	54	81	176	129	172	132	184
f_h/f_α	0.554	0.378	0.442	0.383	0.401	0.357	0.361	0.414	0.313	0.276	0.270	0.265	0.285	0.314	0.50	0.557	0.208	0.52	0.406	0.75	0.478
$\rho \times 10^3$	0.88	0.903	0.888	0.888	0.901	0.888	0.903	0.903	0.908	0.888	0.901	0.896	0.886	0.886	0.886	0.886	0.903	0.886	0.878	0.89	0.88
$v_e/b\omega_\alpha$	4.59	7.10	4.90	6.54	6.91	5.55	5.96	7.25	7.47	6.10	5.84	6.23	5.71	6.67	16.3	11.05	10.1	10.6	8.03	10.4	7.47
ω_e/ω_α	0.726	0.730	0.67	0.655	0.70	0.609	0.66	0.825	0.587	0.547	0.517	0.536	0.513	0.565	0.945	0.962	0.375	0.915	0.85	1.33	1.06
$v_\Lambda/b\omega_\alpha$	2.18	3.83	2.70	3.88	3.65	3.32	3.36	3.90	5.90	3.93	3.61	4.25	3.60	4.31	17.65	10.7	9.95	8.65	5.78	9.93	6.43
$\omega_\Lambda/\omega_\alpha$	0.722	0.68	0.614	0.585	0.708	0.555	0.57	0.62	0.654	0.559	0.535	0.570	0.534	0.594	0.88	0.85	0.55	0.788	0.651	0.98	0.784
v_e/v_Λ	2.1	1.85	1.82	1.68	1.89	1.67	1.77	1.86	1.27	1.55	1.62	1.47	1.59	1.55	0.92	1.03	1.01	1.23	1.39	1.04	1.16

[1]Arbitrary models, round leading edge.

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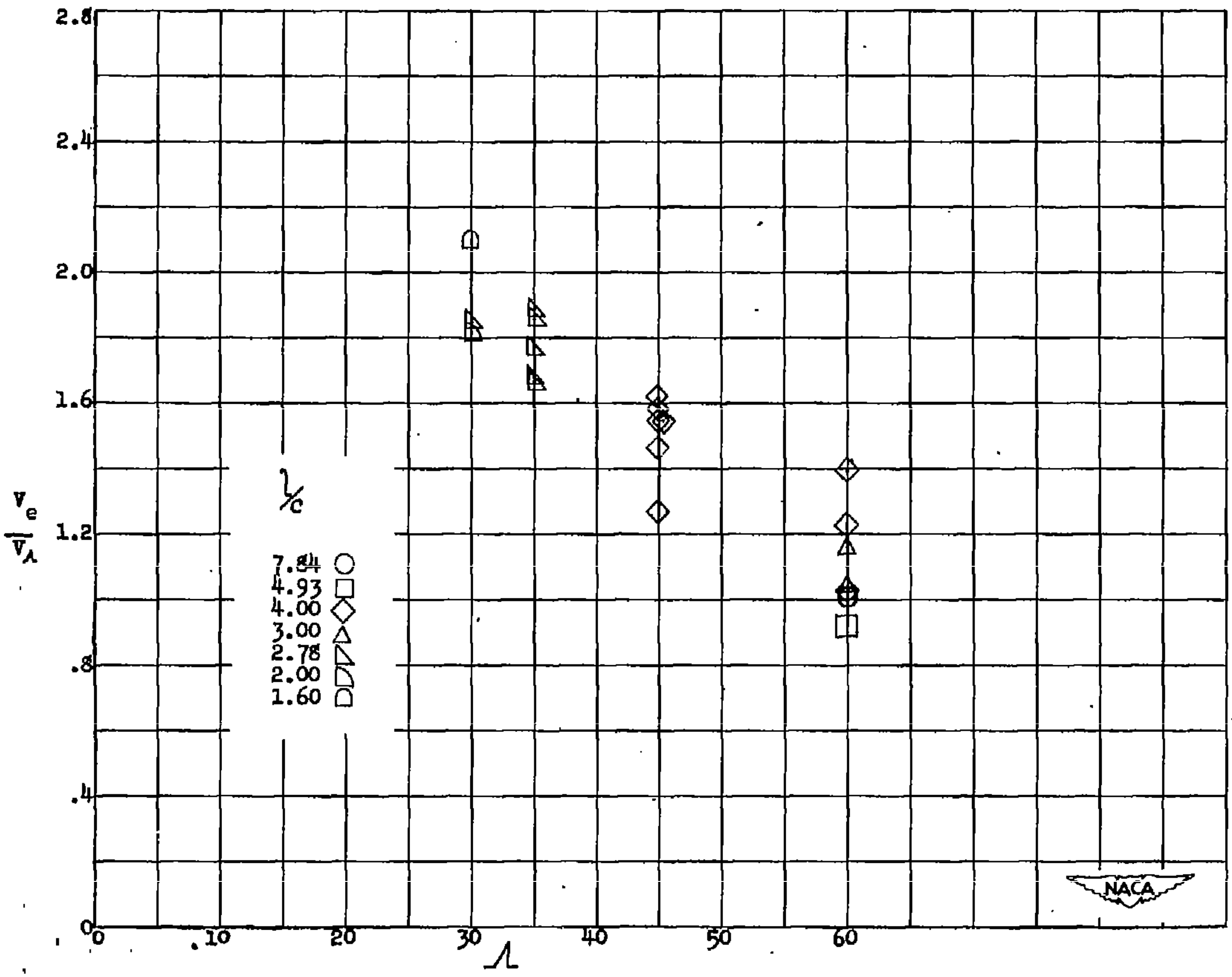

Figure 1.- $\frac{V_e}{V_\Lambda}$ plotted against sweep angle Λ at M = 1.3.

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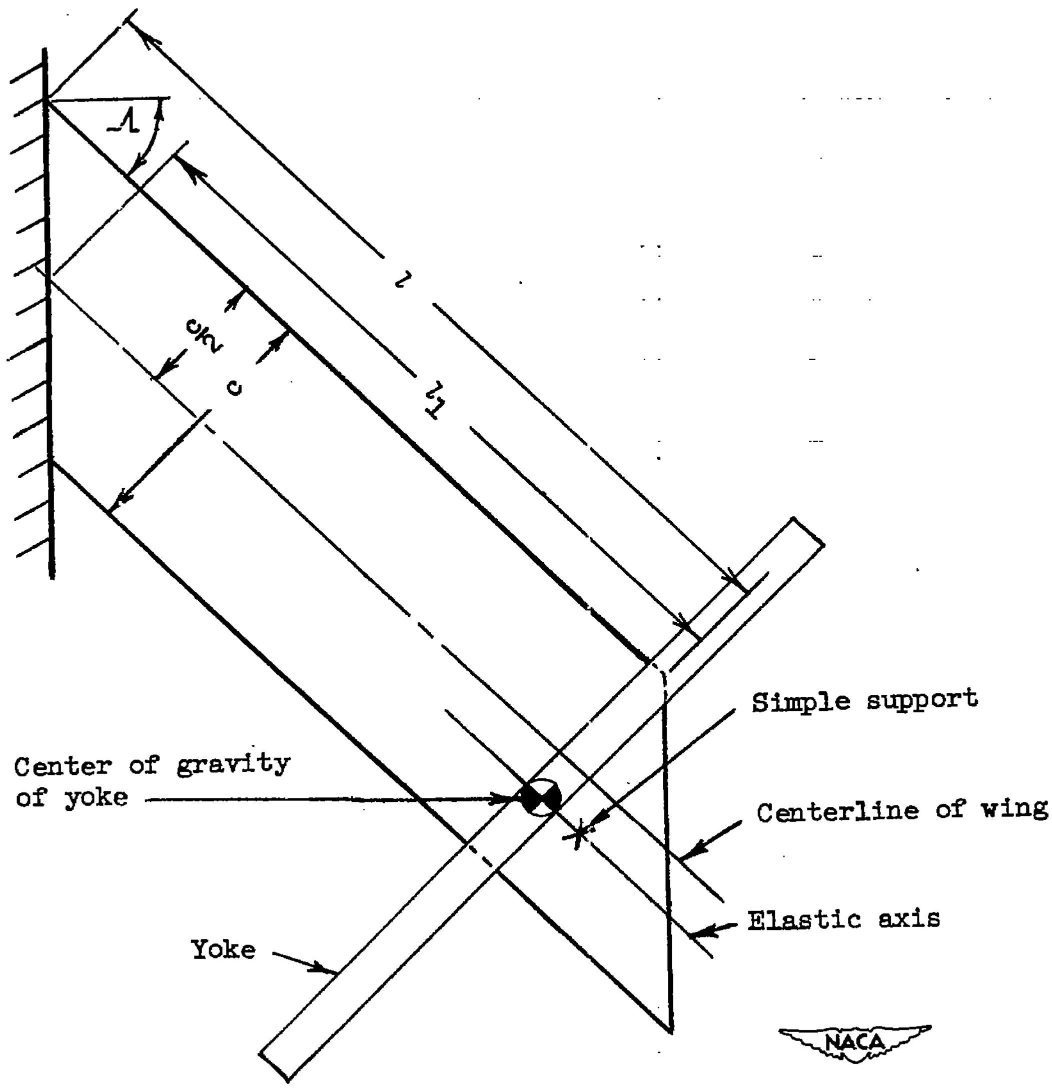

Figure 2.- Sketch of system used for determining uncoupled first torsion frequency.